2001

Final report : SRDC project BSS198 : Improving nutrition management and recommendations by analysing historical soil analysis database

Cook, J

http://hdl.handle.net/11079/955

Downloaded from Sugar Research Australia Ltd eLibrary
FINAL REPORT – SRDC PROJECT BSS198
IMPROVING NUTRITION MANAGEMENT
AND RECOMMENDATIONS BY
ANALYSING HISTORICAL SOIL ANALYSIS DATABASES
by
J Cook*, J Scott* and C Lord*, D R Ridge**
SD01010

* University of New England ** Ross Ridge Consultancy

Principal Investigators:
Gavin McMahon, BSES
Gary Kuhn, Incitec
E-mail: gmcmahon@bses.org.au

Funding for this activity was provided by the sugar industry and the Commonwealth
years, and is gratefully acknowledged. BSES is not a partner, joint venturer, employee
or agent of SRDC and has no authority to legally bind SRDC, in any publication of
substantive details or results of this project.
# TABLE OF CONTENTS

## EXECUTIVE SUMMARY

1.0 BACKGROUND.................................................................................................................. 1
  1.1 General .................................................................................................................. 1
  1.2 Project staff........................................................................................................ 2

2.0 OBJECTIVES.................................................................................................................. 3

3.0 METHODOLOGY ......................................................................................................... 3
  3.1 Establishing databases ....................................................................................... 3
    3.1.1 Incitec data.......................................................................................... 3
    3.1.2 BSES data........................................................................................ 4
  3.2 Database analysis............................................................................................... 4
    3.2.1 Incitec data...................................................................................... 4
    3.2.2 BSES data........................................................................................ 5

4.0 RESULTS......................................................................................................................... 5
  4.1 Database establishment....................................................................................... 5
    4.1.1 Incitec data.......................................................................................... 5
    4.1.2 BSES data........................................................................................ 9
  4.2 Database analysis............................................................................................... 11
    4.2.1 Incitec data...................................................................................... 11
      4.2.1.1 Details of soil analyses.......................................................... 11
      4.2.1.2 District average analytical values (1982-2002) and % low and high values as relevant for each analysis .... 12
      4.2.1.3 Trends in average district analyses and in % low and high values over time............................................. 20
      4.2.1.4 Effect of soil texture on average analyses and % low and high soil analyses in each district...................... 33
      4.2.1.5 Conclusions ................................................................... 36
    4.2.2 BSES data...................................................................................... 38
      4.2.2.1 Details of soil analyses.......................................................... 38
      4.2.2.2 Average trends over all data .............................................. 38
      4.2.2.3 Analysis of district effects................................................. 41
      4.2.2.4 Analysis of soil texture effects on soil analyses in North Queensland and the Herbert.................... 44
      4.2.2.5 Conclusions ................................................................... 46
5.0 OUTPUTS .............................................................................................................. 47
6.0 EXPECTED OUTCOMES .................................................................................. 47
7.0 FUTURE RESEARCH NEEDS .......................................................................... 47
8.0 RECOMMENDATIONS ..................................................................................... 48
9.0 ACKNOWLEDGMENTS ................................................................................... 48
10.0 REFERENCES ..................................................................................................... 48
EXECUTIVE SUMMARY

The aim of this project was to improve and refine nutrient management in the Australian sugar industry by analysis of historical databases of soil test data compiled by BSES from their soil monitoring sites, and by Incitec in the course of providing fertiliser advice to canegrowers. Thus, the project entailed developing easy data interrogation tools to allow BSES and Incitec staff to analyse historical soil nutrient data. The BSES soil monitoring site data covered the period 1975-1994, and the Incitec database the period 1982-2002.

These objectives were achieved to the extent that:

- the BSES data now reside in a stand-alone Microsoft Access database that has incorporated into it a flexible graphing facility that allows a user to define a query and then obtain a graph of the results;
- these data have been analysed to determine trends in soil analyses over time and possible implications for the sugar industry;
- the Incitec database is now located on a Microsoft SQL Server and can be interrogated through a Web site (http://svc9.bne083d.server-web.com/inap/), accessible with a password. The database can be interrogated by district or postcode to obtain trends in means for specified analyses over time, percentage of data falling in a specified range, and to relate analyses to soil texture and colour;
- these data have been analysed to determine trends in soil analyses over time and any possible implications of changes for crop management.

The Incitec database was found to give an excellent representation of general soil fertility of soils in each sugar producing region and of potential problems due to nutrient deficiency, or possible toxicity or other adverse effects. Most soil tests are carried out on from 200 to 1000 samples per district in the different districts each year. Data were available for five State regions, North Queensland, the Herbert, the Burdekin, Central Queensland and South Queensland. This allowed assessment of trends in soil analyses over time with some averaging of data to minimise variability. The use of the BSES database for assessing trends in soil fertility was limited by the restriction of available data to three regions, North Queensland, the Herbert and Central Queensland (Proserpine to Sarina). However, it provided a good index of nutrient trends over time due to repeat analyses on the same sites.

Some of the issues addressed in analysing the databases included:

- the maintenance of soil organic matter levels as a component of soil fertility;
- the effectiveness of current fertiliser programs in maintaining and improving soil fertility;
- the possibility of excess fertiliser use which may impact on the environment;
- the possible build up of soil acidity, alkalinity, salinity or sodicity over time; and
- the identification of emerging nutrient problems.

The most important findings in analysing the industry soil fertility databases are as follows.

- The current conventional fertiliser program for N, P and K appears to be adequate but not excessive in that there does not appear to be a continued build of soil P levels as initially suspected from the BSES soil monitoring sites; K reserves appear to be stable
and low readily available K indicates that current K fertiliser applications are still required; nitrate levels in surface soil are relatively low and are falling in the Burdekin, suggesting that, on average, current N fertiliser applications are not excessive.

- The industry liming program appears to have had an impact in reducing the percentage of soils showing calcium deficiency, particularly in North Queensland and South Queensland; soil pH is also increasing gradually in most districts despite continued use of acidifying urea fertiliser; and the aluminium saturation percentage has fallen in districts with a strong liming program.

- The more widespread use of zinc fertiliser also appears to be having an impact on soil zinc levels, particularly in North and South Queensland. However, the incidence of copper deficiency appears to be increasing slightly and closer attention to copper nutrition may be required.

- Similarly, the incidence of low soil sulfur levels appears to be increasing, and greater attention to the use of sulfur fortified fertiliser is required in marginal soils. The highest percentage of low sulfur soils is in the Burdekin and a change in current practices would be required to prevent sulfur deficiency problems.

- Also in the Burdekin, average soil pH levels are now around 7, with almost 50% of soils tested having a pH above 7. This may be due to expansion onto high clay, alkaline soils and would be a contributing factor to more rapid breakdown of pesticides in Burdekin soils.

- Conflicting results were obtained from the two databases in relation to soil organic C levels, with the Incitec database showing that organic C may be declining in the Burdekin and is relatively stable in other districts. The BSES database showed an apparent increase in organic C levels as a result of trash blanketing. Further investigation of the trend in the Burdekin appears warranted to determine whether the decline in organic C is real and needs to be addressed.

- Recently introduced silicon tests have indicated that a significant proportion of sugar soils are low in silicon. These aspects of soil fertility should be addressed in all districts apart from the Burdekin.

- Manganese levels were shown to be low in North and South Queensland, with the proportion of low Mn soils increasing over time. Similarly, a significant proportion of North Queensland soils had low boron levels. There have been no recorded cases of manganese or boron deficiency in the Australian industry, but the low soil levels suggest that monitoring of leaf levels of these elements should be carried out on marginal soil types to determine whether cane growth is likely to be adversely affected.

- The combined analysis of the Incitec and BSES databases indicates that sandy soils in most districts have the lowest levels of organic C, exchangeable Ca, Mg and K, sulfate-S, copper, zinc and manganese. Higher inputs will therefore be required to maintain fertility of sandy soils.

If the soil fertility issues raised above are addressed this should have a positive long-term impact on industry productivity.
1.0 BACKGROUND

1.1 General

The CANEGROWERS Environmental Audit recognised that fertiliser management within the sugar industry needed improving. Some high priority recommendations of the audit were:

- more participation in soil sampling to determining soil nutrient status; and
- better record keeping of soil analysis and development of regional databases to monitor soil nutrient trends.

In view of this, the existence of historical soil analysis data provided the opportunity to examine nutrient trends across the industry, within different regions and at the farm level if necessary. Apart from providing information relating to nutrient availability, fertiliser recommendations may also be better informed when the existing historic soil test information is readily available. Strategies developed in this way can then reduce environmental impacts of fertiliser, identify emerging problems and increase the efficiency of fertiliser use. Such information can also be useful for choosing future directions of nutrition research.

For the purpose of this project, the sources of data to be analysed were:

1. the BSES soil monitoring site database for all mill areas in Queensland; and
2. the Incitec soil samples results database for sugar districts in Queensland.

The BSES soil fertility monitoring program was commenced in 1975 with 240 monitoring sites established, eight in each of the 30 Queensland mill areas. The sites were located on commercial cane farms, and were selected to represent the major soil types in each mill area. The initial soil sampling was carried out to a depth of 750 mm, at 250 mm intervals. It was intended that subsequent sampling would be carried out to a depth of 250 mm every five years, with deeper sampling each 10 years. Full chemical analysis was to be carried out on the samples to determine trends in soil fertility. An initial analysis of crop components was also carried out at each site to determine potential removal of nutrients in cane and recycling through trash and tops. A later sampling of the soil bulk density profile was carried out for a number of sites to benchmark the compaction status.

The results of the initial sampling were reported by Chapman et al. (1981). Some of the major findings were that most sugar industry soils have adequate phosphorus status; there are low levels of calcium and magnesium in North Queensland soils, and a significant proportion of Burdekin and Mackay soils had low sulfur status. He also reported on crop nutrient uptake.

The maintenance of the soil monitoring sites involved a considerable input by BSES in terms of staff and the laboratory analytical capacity, and while the five-year sampling was relatively successful, subsequent sampling was not carried out in some mill areas.
This report deals with soil analytical results for 35 sites in North Queensland that were sampled on four occasions, and 108 sites in North Queensland and the Central region that were sampled on three occasions. The approximate sampling periods are from 1975-1979, 1980-1984, 1985-1989, and 1990-1994. No analysis of the crop removal data and bulk density profiles has been carried out because these were sampled on only one date.

The Incitec database includes soil analyses carried for cane farmers over the period 1982-2002, both for general fertiliser advice and for troubleshooting of poor growth areas.

The BSES and Incites databases were stored in various forms and format and were not associated with any user-friendly querying tools to obtain results or trends based upon user-defined parameters. Therefore the tasks were to:

1. identify and analyse the source data in each database;
2. create suitable database structures in which to store the data;
3. import all historic data into the created database structures;
4. create tools to allow for continued importation of Incitec sample data into the database and quality control of the data;
5. create tools for managing the Incitec database to enable its use over the long term;
6. create tools for the user-friendly interrogation of the databases to obtain defined trend data and/or graphs so that the data could be analysed quickly and easily to achieve the recommendations required;
7. analyse trends in soil analyses over time in both the BSES and Incitec databases and identify any changes with significance for future crop management.

1.2 Project staff

Key project personnel included:

**Bureau of Sugar Experiment Stations (BSES)**
Project Manager: Mr Gavin McMahon

**Incitec Pty Ltd**
Project Managers: Mr Gary Kuhn, Mr Jack Rohde

**University of New England (UNE), Armidale**
Principal Investigator: Assoc. Prof. Jim Scott, Agronomy and Soil Science, School of Rural Science and Natural Resources
Programmer: Mr Jim Cook, Database Programmer, Agronomy and Soil Science, School of Rural Science and Natural Resources
Programmer: Mr Colin Lord, Database Programmer, Agronomy and Soil Science, School of Rural Science and Natural Resources

**Ross Ridge Consultancy**
Data trend analysis: Mr Ross Ridge
2.0 OBJECTIVES

The aim of this project was to improve and refine nutrient management in the Australian sugar industry using historical databases of soil test data in order to minimise off-site impacts and increase nutrient use efficiency. Thus, the project entailed developing easy data interrogation tools to allow BSES and Incitec staff to analyse soil nutrient data.

These objectives were achieved to the extent that:

- the BSES data reside in a stand-alone Microsoft Access database that has incorporated into it a flexible graphing facility that allows a user to define a query and then obtain a graph of the results;
- these data have been analysed to determine trends in soil analyses over time and possible implications for the sugar industry;
- the Incitec database is now located on a Microsoft SQL Server and can be interrogated through a Web site (http://svc9.bne083d.server-web.com/inap/), accessible with a password. The database can be interrogated by district or postcode to obtain trends in means for specified analyses over time, percentage of data falling in a specified range, and to relate analyses to soil texture and colour;
- these data have been analysed to determine trends in soil analyses over time and any possible implications of changes for crop management;
- the recommendations of this report have been circulated to all agronomists and advisory staff to be included in nutrient recommendation programs.

3.0 METHODOLOGY

3.1 Establishing databases

3.1.1 Incitec data

The establishment of the Incitec database involved the following.

- Analysis of the expected data, and design and testing of a preliminary database.
- Creation of the 'final' database.
- Identification and importation of all relevant historical soil, plant, sap and water sample data into the database, including filtering of anomalous data.
- Clarification of data and data transfer format for future importing of data into the database.
- Creation and testing of flexible data import and quality control tools.
- Creation of forms that allow specific data sets to be classified into standard groups for ease of interrogation of the data (sample depth, crops sampled, soil colour, soil texture, postcodes).
- Creation of numerous tools to enable addition of, for example, sample types, sample products, analytes.
- Creation of an Internet based, user definable data querying facility.
3.1.2 BSES data

The BSES data for the soil monitoring sites includes:

- soil bulk density;
- soil analysis;
- crop nutrients;
- crop data.

The establishment of the database in a form readily available to users involved:

- identifying the nature and scope of the data;
- modifying the current database to receive the data;
- incorporating a tool to interrogate the data allowing users to refine queries to obtain the desired information;
- provision of a facility for either exporting the data to Excel or an alternative spreadsheet, or graphing the data as required.

This report deals with soil analytical results for 35 sites in North Queensland that were sampled on four occasions, and 108 sites in North Queensland and the Central region that were sampled on three occasions. The approximate sampling periods are from 1975-1979, 1980-1984, 1985-1989, and 1990-1994. Data for analysis of trends was extracted from the database established for BSES by the University of New England for the above sites. Only soil analytical results and site details have been analysed because these are the only data suitable for determining trends over time.

3.2 Database analysis

3.2.1 Incitec data

The Incitec database was analysed on a region by region basis for North Queensland, the Herbert (Ingham), the Burdekin, Central Queensland (Proserpine-Sarina), and South Queensland (Bundaberg-Rocky Point). The North Queensland data includes the Atherton Tableland. In general, analyses were available for the period 1982 to 2002, but some analyses were available over a limited time period, due either to recent introduction of the analytical technique or apparent anomalies in early data. These analyses included extractable boron, exchangeable aluminium% of CEC, nitric acid extractable potassium, BSES silicon, calcium chloride extractable silicon and exchangeable sodium%. It was advised by Incitec that a number of the samples analysed in sugar districts were not specifically identified as from sugarcane blocks, and these samples were not included in the sugarcane database. After investigation all samples from sugarcane districts were included in this study, because it appeared that most were from sugarcane blocks, and average nutrient values were similar between the two groups of samples. Some filtering of data was carried out by setting a lower and higher limit for each nutrient in case there were any atypical data on the database. This was particularly important for North Queensland samples where the total database showed some divergence from the smaller sugarcane database.
The Incitec database was interrogated to determine trends in analyses over time, average district nutrient levels, the percentage of low (possible deficiency) or high (possible toxicity or other problems) values as relevant for a particular analysis, and the effect of soil texture on analyses. The number of analyses available in the database varied between nutrients and in some cases the small number of samples available made it difficult to establish any meaningful trends in nutrient levels over time. Similarly, where only a few years’ data were available, it was not possible to determine a trend over time. To facilitate plotting of trends over time a moving two-year average was calculated for each set of analyses.

3.2.2 BSES data

The BSES soil database was analysed by determining trends in nutrient analyses over time on a district-by-district basis, and the effect of soil texture on these trends. Where relevant the proportion of samples showing potential nutrient deficiency was also determined. These data include only North Queensland, the Herbert and the Central regions due to the discontinuation of sampling in other districts and cover the period 1975-1994 in contrast to the 1982-2002 period for the Incitec data.

4.0 RESULTS

4.1 Database establishment

4.1.1 Incitec data

The Incitec data now reside on a Microsoft SQL database server and are accessible via a Web page on the Internet (initially http://rdu.une.edu.au/, but now http://svc9.bne083d.server-web.com/inap/). The historical data imported to the database contain in excess of 600,000 records covering the period 1981-2002. Some of the tools provided for the database management are as follows.

- Tools to import future data using any of a number of user defined import template masks.
- Data import quality control and the facility to discard or reprocess failed samples.
- A suite of tools to allow the database manager to add on to and change the current database as the need arises.
- A suite of tools to allow the hundreds and, in some cases, thousands of different entries in sample definition fields to be assigned to a smaller manageable number of classifications. For example, there are over 20,000 crop sampled entries.
- Tracking of database manipulation activities.
- Internet delivery of the data using a sequence of pages that allow a user to define a specific query for creation of a table of data as required.

The Web pages guide the user through a number of query definition screens and then the results are displayed in tabular form - this can readily be copied into Excel for graphing.

Figures 1, 2 and 3 are examples of the Web interface created for users to interrogate the Incitec data.
Figure 1. Screen 1 of the Incitec database query Web page.

Figure 2. Screen 2 of the Incitec database query Web page.
Figure 4 is an example of the output generated by such a query of the Incitec data. Figure 5 is an example form from the Microsoft Access database maintenance tool created for use by Incitec to import data and maintain the database into the future.
Typical user choices include:

- crop types;
- test types (soil, water, plant or sap);
- areas to be included in the query (regions to postcodes);
- soil types (colours and textures);
- which tests to include in the output;
- 1, 5 or 10 year averages;
- how the data are to be displayed (means, medians or percentiles).
4.1.2 BSES data

The BSES data have been stored within a suitably structured Microsoft Access Database. A flexible data trend analysis graphing tool (FlexiGraph) has been included to assist in analysis of the data. CD-ROMs of the database have been provided for BSES research staff.

Figures 6 and 7 are examples of the flexible graphing interface used to interrogate the BSES data, whilst Figures 8 and 9 are examples of the graphical output from the BSES soil research database.

![Graphing Interface](image)

Figure 6. First screen of BSES data graphing facility.

Step 1:

- Select the data set
- Select the data to be displayed (X Axis, Y Axis and Series)
- Select the type of graph (line, bar …)
- Select how the data are collated
- Adjust the graph properties if desired
Step 2 involves restricting the data to only that data that one wants to display. For example, a user may wish to look at the differences between BSES P in greater soil groups for each region. In step 1 the user selected BSES P as the data and greater soil group as the series. In Step 2 the user may wish to restrict the data to one or more regions or mills (i.e., Region 2, Mill Mourilyan) so that only data from that area are considered in the final graph.

Figure 7. Second of the data query defining screens from the BSES data graphing facility.

Figure 8. Example of output from the BSES data graphing facility looking at changes in BSES P through time for all soil types within the mill area for Mourilyan.
4.2 Database analysis

4.2.1 Incitec data

4.2.1.1 Details of soil analyses

The analyses in the Incitec database that are considered most relevant in assessing soil fertility for the sugarcane industry are listed in Table 1. These analyses are similar to those used by BSES and, where there are differences, the exchange of sample between Incitec and BSES over a number of years has established a relationship between different analytical methods.

TABLE 1. Soil analyses extracted from the Incitec database for analysis of soil fertility levels in the sugar industry.

<table>
<thead>
<tr>
<th>Soil analyses</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH H₂O</td>
<td></td>
</tr>
<tr>
<td>Conductivity (1:5 water) dS/m</td>
<td></td>
</tr>
<tr>
<td>Exchangeable Sodium % (ESP)</td>
<td></td>
</tr>
<tr>
<td>Organic C %</td>
<td></td>
</tr>
<tr>
<td>P BSES mg/kg</td>
<td></td>
</tr>
<tr>
<td>K Amm Acet me%</td>
<td></td>
</tr>
<tr>
<td>Nitric K me%</td>
<td></td>
</tr>
<tr>
<td>Ca Ammon Acet me%</td>
<td></td>
</tr>
<tr>
<td>Mg Ammon Acet me%</td>
<td></td>
</tr>
<tr>
<td>Aluminium Saturation %</td>
<td></td>
</tr>
<tr>
<td>Nitrate N mg/kg</td>
<td></td>
</tr>
<tr>
<td>SO₄-S MCP mg/kg</td>
<td></td>
</tr>
<tr>
<td>Fe DTPA mg/kg</td>
<td></td>
</tr>
<tr>
<td>Mn DTPA mg/kg</td>
<td></td>
</tr>
<tr>
<td>Si BSES (0.005H₂SO₄) mg/kg</td>
<td></td>
</tr>
<tr>
<td>Si (CaCl₂) mg/kg</td>
<td></td>
</tr>
<tr>
<td>Cu DTPA mg/kg</td>
<td></td>
</tr>
<tr>
<td>Zn DTPA mg/kg</td>
<td></td>
</tr>
<tr>
<td>Zn BSES HCl extract mg/kg</td>
<td></td>
</tr>
<tr>
<td>B (hot water, CaCl₂ extract)</td>
<td></td>
</tr>
</tbody>
</table>
4.2.1.2 District average analytical values (1982-2002) and % low and high values as relevant for each analysis

The district average analytical values over the period 1982 to 2002 values are summarised in Table 2. The average numbers of samples analysed per district per year for each analysis are summarised in Table 3. It should be noted that some samples have been excluded from these figures due to the screening of individual analyses to exclude excessively high or low values. For ESP the sampling period is 1993-2002, for boron 1994-2002, for BSES nitric K, aluminium saturation % and Zn HCl extract 1995-2002, for BSES Si 2000-2002 and for CaCl2 Si 2002. The 1992 data are absent from all these tables because they were not included in the database.

The district average percentage of low (possible deficiency) and high (possible toxicity or other problems) analyses for each analytical method is summarised in Table 4.

The summary data are discussed below in relation to each individual analysis.

**Organic carbon**

Organic carbon figures are lowest in the Burdekin district, highest in North Queensland and South Queensland, and levels are intermediate in the Herbert and Central districts. A limited number of samples were available for the Herbert and the average figures may be less reliable in this district. Average district organic carbon levels range from 0.99 to 1.71%. The percentage of samples with very low organic carbon levels (<0.5%) was greatest in the Burdekin (11.3%), as expected from the low overall average organic C level of 0.99%.

**pH (1:5 water)**

The average district pH level ranged from 5.2 in the Herbert to 6.86 in the Burdekin. While low pH or high pH alone is not considered detrimental to cane growth, the overall pH status in each district was further rated in terms of percentage of sites with pH <5 (all districts apart from the Burdekin), or percentage of sites with pH>7 (Burdekin). As expected the Herbert had the highest percentage of low pH samples (44.3), followed by North Queensland and the Central region. The Burdekin had 40% of samples with a pH>7, and this is likely to be contributing to the more rapid breakdown of pesticides in Burdekin soils.

**EC (1:5 extract)**

The average electrical conductivity of soil samples from each district is relatively low, but is highest in the Burdekin and Southern regions. Similarly, the Burdekin and Bundaberg regions have 11.9 and 6.5%, respectively, of samples with an EC>0.2, where some salinity effect on cane growth may be expected, depending on soil texture.

**Calcium**

The average soil calcium status was highest in the Burdekin and lowest in North Queensland with a range of 1.62 to 8.52 me% in mean values. In North Queensland, 17.3% of samples analysed between 1982 and 2002 had apparent calcium deficiency.
Ca<0.55 me%), and 27.8% marginal levels (Ca 0.55-1.25 me%). Moderate levels of Ca deficiency or marginal Ca levels were also evident in samples from the Herbert and South Queensland, with slightly better calcium status in the Central region. There were only a minor proportion of low calcium sites in the Burdekin.

**Magnesium**

The magnesium status of soils was also highest in the Burdekin and lowest in North Queensland, with average values ranging from 0.66 to 4.84 me%. Magnesium deficiency was less pronounced than calcium deficiency with 4.8% of North Queensland samples showing deficiency, and 19.1% with marginal magnesium levels. In the remaining districts the level of deficiency followed the order Herbert> Southern region> Central region and the Burdekin.

**Potassium**

Potassium levels are assessed as readily available K (ammonium acetate extract) and potassium reserves (nitric acid extractable K). Readily available potassium was highest in Burdekin soils (mean of 0.3 me%), and these generally receive no potassium fertiliser. The next highest average levels were in South Queensland soils (0.26 me%) followed by the remaining districts (0.21-0.22 me%). In the Burdekin area, only 4.3% of soils had low potassium levels (<0.12 me%), with a range of 19.7 to 25.3% in the remaining districts.

The highest nitric K reserves for the period 1995 to 2002 occurred in the Burdekin (mean 2.70 me%), followed by North Queensland (1.98 me%), the Herbert (1.82 me%), the Central region (1.15 me%) and the Southern region (0.84 me%). The low nitric K values in the Southern region are reflected in 36.2% of samples having reserves <0.6 me%, with the Central region having 21.1%, and North Queensland 17.7% of analyses <0.6 me%. Both the Herbert and Burdekin regions had very few soils with K reserves < 0.6 me% (<2%).

**Exchangeable sodium percentage (ESP)**

The average ESP for the period 1993 to 2002 was highest in the Burdekin (6.2%), followed by the Southern region (5.8%), the Central region (3.9%), the Herbert (3.5%) and North Queensland (1.9%). If an ESP of >15 is used as an indicator of soils seriously affected by high sodium levels, the Burdekin soils have the greatest sodium hazard (7.7%>15), followed by the Southern region (5.8%), the Central region (3.2%) and the Herbert (2.4%). There were no high ESP levels in North Queensland samples. There would be a need to take these high sodium levels into account in managing affected soils, particularly in the Burdekin and Southern regions.

The samples included in the database are almost exclusively from surface soil and it is expected that they would underestimate potential sodium problems.

**Aluminium saturation %**

The data on aluminium saturation % for the period 1995 to 2002 showed the highest average levels in North Queensland (33.9%), followed by the Herbert, South Queensland and the Central region. The aluminium saturation levels are low in the Burdekin, as
expected. Using 50% aluminium saturation as an index of possible direct or indirect effects on sugarcane growth the main effects are likely in North Queensland (25% of samples), followed by the Herbert (17%), the Southern region (6%) and the Central region (5.1%). This cut-off level overestimates the possible adverse affect of high aluminium levels and it is unlikely that cane growth would be affected provided soil calcium levels were adequate. For example, in North Queensland only 5% of sites had an aluminium saturation %>70, where aluminium toxicity may be a potential problem.

**Phosphorus (BSES)**

The average BSES P levels ranged from 46 mg/kg in the Central region to 73 mg/kg in the Burdekin, where minimal application of phosphate fertiliser is required. In general the relatively high BSES P levels reflect the long history of P fertiliser use in regions other than the Burdekin. The proportion of samples showing deficiency was assessed using a cut-off point of 11 mg/kg P. This ranged from 10.6% in the Southern region to 6.7% in the Burdekin. The current fertiliser recommendations based on soil test results should cater adequately for these deficient sites.

**Sulfur (as SO₄-S)**

Average soil S levels were highest in the North Queensland and South Queensland regions (19-21 mg/kg), followed by the Herbert and Burdekin (14 mg/kg), and the Central region (11 mg/kg). The percentage of samples with low sulfur levels (<3 mg/kg) ranged from 17% in the Burdekin to 6.4% in the Herbert. The Burdekin figures are unexpected and it may be necessary to apply sulfur fortified fertiliser in low S areas of the Burdekin. The current practice of recommending use of sulfur fortified fertiliser on soils with low S status should be adequate to minimise problems with S deficiency in other districts.

**Nitrate nitrogen**

In general, average nitrate nitrogen levels were moderate for all districts ranging from a high of 11 mg/kg in the Burdekin to 8 mg/kg in the Central region. While this soil test is not usually used in deciding nitrogen fertiliser requirements, an assessment of soil nitrogen status was made by computing the percentage of soils with NO₃-N <4.9 mg/kg.

This was similar in all districts, ranging from 52% in the Central region to 40% in North Queensland. In general, the reserves of NO₃-N are relatively low, as indicated by these figures and higher levels would only be expected after a bare fallow or following a legume or small crop.

**Iron**

The average iron levels ranged from 55 mg/kg in the Burdekin to 115 mg/kg in the Herbert. The incidence of iron deficiency in sugar soils is generally transient according to prevailing conditions favouring oxidation or reduction of iron, but an approximate index of low iron levels was obtained by computing the percentage of samples with Fe <10 mg/kg. This was very low, ranging from 0.8% in the Herbert to 3.4% in North Queensland where temporary iron deficiency is most prevalent.
Manganese

Average district manganese levels varied over a relatively narrow range from 15 mg/kg in the Burdekin to 24 mg/kg in the Herbert. Again levels of extractable Mn fluctuate with soil conditions, but soils with Mn<5.9 mg/kg are considered to have a low Mn status. The percentage of low Mn soils followed the order South Queensland (41%) > North Queensland (31%) > Burdekin (21%) > Central Queensland (17%) > the Herbert (12%). The relatively high percentage of low Mn values in most districts suggests that a watching brief should be kept for Mn deficiency.

Copper

The average DTPA Cu levels were highest in the Southern region (1.5 mg/kg) and the Burdekin (1.4 mg/kg) and lowest in North Queensland (0.8 mg/kg). Again the Cu soil test is only an approximate indicator of low Cu levels, but soils with Cu< 0.22 mg/kg are considered to have a low Cu status. The percentage of samples with low Cu status was highest in South Queensland, the Herbert and North Queensland (22-18%), followed by the Central district (14%) and the Burdekin (1%). While the percentage of low Cu soils is relatively high, at risk soils will normally receive copper applications under current practices.

Zinc

The database includes Zn analyses in both DTPA and HCl extracts (BSES Zn), and the latter is considered most applicable to a majority of sugar districts where soils are acidic. The exception is the Burdekin where the DTPA extract may be more appropriate. Average BSES Zn levels for the period 1995-2002 are highest in the Burdekin (2.1 mg/kg) and lowest in the Central region (1.3 mg/kg). The average DTPA Zn for Burdekin is 1.4 mg/kg. Soils with BSES Zn levels <0.6 mg/kg are considered to have a high risk of Zn deficiency. The incidence of low Zn soils follows the order South Queensland (39%) > Central Queensland (33%) > the Herbert (24%) > North Queensland (21%) and the Burdekin (13%). In the Burdekin, the DTPA Zn test indicates that 9% of soils are low in Zn (<0.6 mg/kg). With the exception of the Burdekin the above figures indicate that the incidence of low Zn soils is relatively high, and more widespread use of Zn fertiliser may be required.

Boron

Reliable boron soil analyses were considered to be available only for the period 1994-2002. Average boron levels ranged from 0.49 to 0.77 mg/kg in the different districts. Soils with B analyses < 0.15 mg/kg were considered marginal. These comprised 19% of samples in North Queensland, 9% in Central Queensland and 3-5% in other districts. Boron deficiency has not been identified in the Australian industry but is most likely in North Queensland based on the above figures.
**Silicon**

Silicon levels in soils are currently assessed using a CaCl$_2$ extract for readily available Si and a dilute sulfuric acid extract to indicate silicon reserves (BSES Si). Average silicon reserves ranged from 536 mg/kg in the Burdekin to 134-155 mg/kg in the remaining districts. Similarly, readily available Si averaged 51 mg/kg in the Burdekin and 15-22 mg/kg in the remaining districts.

The silicon reserves are considered to be marginal below 70 mg/kg, and readily available Si marginal below 10 mg/kg. Reserves were lowest in South Queensland (36% of samples < 70 mg/kg), followed by North Queensland, the Herbert and Central Queensland (19-22%), and the Burdekin (2%). The proportion of sites with low readily available silicon (< 10 mg/kg) followed the order South Queensland (37%) > the Herbert (25%) > North Queensland and the Central region (15-18%) and the Burdekin (2%). As for Zn there is a relatively high proportion of samples with low silicon status in most districts and responses to silicon application could be expected.
### TABLE 2. District average analytical values over the period 1982-2002

<table>
<thead>
<tr>
<th>District</th>
<th>Org C %</th>
<th>pH</th>
<th>EC mS/m</th>
<th>Ca me%</th>
<th>Mg me%</th>
<th>K me%</th>
<th>Nitric K me%</th>
<th>ESP</th>
<th>Al Sat %</th>
<th>P Mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Qld</td>
<td>1.71</td>
<td>5.44</td>
<td>0.05</td>
<td>1.62</td>
<td>0.66</td>
<td>0.21</td>
<td>1.98</td>
<td>1.87</td>
<td>33.9</td>
<td>59.7</td>
</tr>
<tr>
<td>Herbert</td>
<td>1.28</td>
<td>5.20</td>
<td>0.08</td>
<td>2.45</td>
<td>1.24</td>
<td>0.21</td>
<td>1.82</td>
<td>3.52</td>
<td>29.5</td>
<td>47.4</td>
</tr>
<tr>
<td>Burdekin</td>
<td>0.99</td>
<td>6.86</td>
<td>0.12</td>
<td>8.52</td>
<td>4.84</td>
<td>0.30</td>
<td>2.70</td>
<td>6.24</td>
<td>6.8</td>
<td>72.7</td>
</tr>
<tr>
<td>Central Qld</td>
<td>1.25</td>
<td>5.44</td>
<td>0.05</td>
<td>3.38</td>
<td>2.11</td>
<td>0.22</td>
<td>1.15</td>
<td>3.92</td>
<td>18.6</td>
<td>46.4</td>
</tr>
<tr>
<td>South Qld</td>
<td>1.53</td>
<td>5.69</td>
<td>0.08</td>
<td>3.11</td>
<td>1.81</td>
<td>0.26</td>
<td>0.84</td>
<td>5.76</td>
<td>20.3</td>
<td>62.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>SO$_4$-S mg/kg</th>
<th>NO$_3$-N mg/kg</th>
<th>Fe mg/kg</th>
<th>Mn mg/kg</th>
<th>Cu mg/kg</th>
<th>Zn DTPA mg/kg</th>
<th>Zn HCl mg/kg</th>
<th>B mg/kg</th>
<th>Si BSES mg/kg</th>
<th>Si CaCl$_2$ mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Qld</td>
<td>20.6</td>
<td>8.1</td>
<td>66.8</td>
<td>17.0</td>
<td>0.76</td>
<td>0.95</td>
<td>1.47</td>
<td>0.49</td>
<td>148.1</td>
<td>15.2</td>
</tr>
<tr>
<td>Herbert</td>
<td>13.8</td>
<td>8.5</td>
<td>115.3</td>
<td>24.1</td>
<td>0.81</td>
<td>1.37</td>
<td>1.77</td>
<td>0.55</td>
<td>145.9</td>
<td>18.3</td>
</tr>
<tr>
<td>Burdekin</td>
<td>14.1</td>
<td>11.0</td>
<td>54.6</td>
<td>15.0</td>
<td>1.37</td>
<td>1.39</td>
<td>2.09</td>
<td>0.63</td>
<td>536.3</td>
<td>50.5</td>
</tr>
<tr>
<td>Central Qld</td>
<td>10.6</td>
<td>8.0</td>
<td>105.8</td>
<td>21.0</td>
<td>0.98</td>
<td>1.20</td>
<td>1.28</td>
<td>0.54</td>
<td>155.5</td>
<td>21.9</td>
</tr>
<tr>
<td>South Qld</td>
<td>19.4</td>
<td>10.7</td>
<td>96.6</td>
<td>18.9</td>
<td>1.52</td>
<td>2.04</td>
<td>1.60</td>
<td>0.77</td>
<td>133.7</td>
<td>19.8</td>
</tr>
<tr>
<td>District</td>
<td>Org C %</td>
<td>pH</td>
<td>EC mS/m</td>
<td>Ca me%</td>
<td>Mg me%</td>
<td>K me%</td>
<td>Nitric K me%</td>
<td>ESP</td>
<td>Al Sat %</td>
<td>P Mg/kg</td>
</tr>
<tr>
<td>------------------</td>
<td>---------</td>
<td>-----</td>
<td>---------</td>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>--------------</td>
<td>-----</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>North Qld</td>
<td>755</td>
<td>1013</td>
<td>843</td>
<td>717</td>
<td>915</td>
<td>678</td>
<td>299</td>
<td>1056</td>
<td>515</td>
<td>949</td>
</tr>
<tr>
<td>Herbert</td>
<td>80</td>
<td>278</td>
<td>255</td>
<td>261</td>
<td>266</td>
<td>216</td>
<td>233</td>
<td>275</td>
<td>234</td>
<td>253</td>
</tr>
<tr>
<td>Burdekin</td>
<td>186</td>
<td>322</td>
<td>316</td>
<td>319</td>
<td>321</td>
<td>289</td>
<td>220</td>
<td>376</td>
<td>16</td>
<td>324</td>
</tr>
<tr>
<td>Central Qld</td>
<td>159</td>
<td>763</td>
<td>692</td>
<td>744</td>
<td>762</td>
<td>702</td>
<td>858</td>
<td>880</td>
<td>616</td>
<td>747</td>
</tr>
<tr>
<td>South Qld</td>
<td>428</td>
<td>647</td>
<td>622</td>
<td>602</td>
<td>618</td>
<td>580</td>
<td>282</td>
<td>654</td>
<td>303</td>
<td>627</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>District</th>
<th>SO₄-S mg/kg</th>
<th>NO₃-N mg/kg</th>
<th>Fe mg/kg</th>
<th>Mn mg/kg</th>
<th>Cu mg/kg</th>
<th>Zn DTPA mg/kg</th>
<th>Zn HCl mg/kg</th>
<th>B mg/kg</th>
<th>Si BSES mg/kg</th>
<th>Si CaCl₂ mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Qld</td>
<td>827</td>
<td>666</td>
<td>856</td>
<td>822</td>
<td>704</td>
<td>733</td>
<td>445</td>
<td>914</td>
<td>690</td>
<td>326</td>
</tr>
<tr>
<td>Herbert</td>
<td>309</td>
<td>63</td>
<td>145</td>
<td>152</td>
<td>172</td>
<td>178</td>
<td>215</td>
<td>65</td>
<td>252</td>
<td>105</td>
</tr>
<tr>
<td>Burdekin</td>
<td>307</td>
<td>173</td>
<td>202</td>
<td>202</td>
<td>206</td>
<td>213</td>
<td>116</td>
<td>177</td>
<td>125</td>
<td>82</td>
</tr>
<tr>
<td>Central Qld</td>
<td>720</td>
<td>148</td>
<td>194</td>
<td>197</td>
<td>223</td>
<td>197</td>
<td>197</td>
<td>109</td>
<td>597</td>
<td>310</td>
</tr>
<tr>
<td>South Qld</td>
<td>566</td>
<td>368</td>
<td>418</td>
<td>430</td>
<td>487</td>
<td>455</td>
<td>253</td>
<td>365</td>
<td>404</td>
<td>81</td>
</tr>
</tbody>
</table>
TABLE 4. District average % of samples with low (possible deficiency) or high (possible toxicity or other adverse reaction) values for each soil characteristic over the period 1982-2002

<table>
<thead>
<tr>
<th>District</th>
<th>Org C &lt;0.5 %</th>
<th>pH &lt;5 or &gt;7</th>
<th>EC &gt;0.2 mS/m</th>
<th>Ca &lt;0.55 me%</th>
<th>Mg &lt;0.1 me%</th>
<th>K &lt;0.12 me%</th>
<th>Nitric K &lt;0.6 me%</th>
<th>ESP &gt;15</th>
<th>Al Sat % &gt;50</th>
<th>P &lt;11 mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Qld</td>
<td>5.6</td>
<td>31.7</td>
<td>0.2</td>
<td>17.3(27.8)</td>
<td>4.8(19.1)</td>
<td>20.2</td>
<td>17.7</td>
<td>0</td>
<td>25.0</td>
<td>8.6</td>
</tr>
<tr>
<td>Herbert</td>
<td>7.8</td>
<td>44.3</td>
<td>3.7</td>
<td>8.6(24.0)</td>
<td>2.0(11.4)</td>
<td>19.7</td>
<td>0.2(4.3)</td>
<td>3.2</td>
<td>5.1</td>
<td>10.6</td>
</tr>
<tr>
<td>Burdekin</td>
<td>11.3</td>
<td>40.0**</td>
<td>11.9</td>
<td>1</td>
<td>0.2(4.3)</td>
<td>4.3</td>
<td>0.2(4.3)</td>
<td>3.2</td>
<td>5.1</td>
<td>10.6</td>
</tr>
<tr>
<td>Central Qld</td>
<td>7.3</td>
<td>24.9</td>
<td>2.4</td>
<td>4.7(15.3)</td>
<td>0.6(4.1)</td>
<td>21.2</td>
<td>21.1</td>
<td>3.2</td>
<td>5.1</td>
<td>10.6</td>
</tr>
<tr>
<td>South Qld</td>
<td>3.4</td>
<td>17.5</td>
<td>6.5</td>
<td>8.8(19.0)</td>
<td>1.1(6.7)</td>
<td>25.3</td>
<td>36.2</td>
<td>5.8</td>
<td>9.0</td>
<td>9.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>District</th>
<th>SO₄-S &lt;3 mg/kg</th>
<th>NO₃-N &lt;4.9 mg/kg</th>
<th>Fe &lt;10 mg/kg</th>
<th>Mn &lt;5.9 mg/kg</th>
<th>Cu DTPA &lt;0.22 mg/kg</th>
<th>Zn DTPA &lt;0.6 mg/kg</th>
<th>Zn HCl &lt;0.15 mg/kg</th>
<th>B &lt;70 mg/kg</th>
<th>Si BSES &lt;10 mg/kg</th>
<th>Si CaCl₂ &lt;10 mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Qld</td>
<td>7.8</td>
<td>40.4</td>
<td>3.4</td>
<td>31.3</td>
<td>18.1</td>
<td>12.3</td>
<td>21.3</td>
<td>19.3</td>
<td>22.0</td>
<td>15.2</td>
</tr>
<tr>
<td>Herbert</td>
<td>6.4</td>
<td>43.8</td>
<td>0.8</td>
<td>12.3</td>
<td>19.3</td>
<td>10.3</td>
<td>24.1</td>
<td>5.0</td>
<td>19.8</td>
<td>24.8</td>
</tr>
<tr>
<td>Burdekin</td>
<td>17.1</td>
<td>45.2</td>
<td>1.5</td>
<td>21.3</td>
<td>1.4</td>
<td>8.8</td>
<td>13.1</td>
<td>2.5</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Central Qld</td>
<td>8.9</td>
<td>52.2</td>
<td>1.6</td>
<td>16.9</td>
<td>14.2</td>
<td>13.3</td>
<td>32.8</td>
<td>9.4</td>
<td>18.5</td>
<td>18.4</td>
</tr>
<tr>
<td>South Qld</td>
<td>11.1</td>
<td>44.0</td>
<td>1.6</td>
<td>40.7</td>
<td>22.2</td>
<td>12.9</td>
<td>38.5</td>
<td>3.0</td>
<td>36.4</td>
<td>37.3</td>
</tr>
</tbody>
</table>

** % >7

( ) additional percentage with marginal Ca (0.55-1.25), or marginal Mg (0.1-0.3)
4.2.1.3 Trends in average district analyses and in % low and high values over time

The trends in average district analyses for different soil tests were computed over the period 1982-2002 in most cases and for shorter periods where tests were commenced later than 1982. These trends were calculated as a running two year average with weighting of years by sample number. Similarly, trends in percentage low (or deficient) sites or percentage high (or toxic) sites were computed for the range of soil tests. The trends for each soil test are presented below.

**Organic C**

The trends in organic C levels over time are presented in the Figures 10 and 11. There are no clear-cut trends in organic C levels over the period 1982 to 2002, but there is a slight apparent downturn in the North Queensland, Herbert and South Queensland districts in towards the end of the test period. This is also reflected in a slight increase in the percentage of samples with organic C < 0.5 %.
Trends in soil pH over time and in the percentage of samples with pH < 5 or > 7 are indicated in the Figures 12 and 13.

The trend in soil pH in all districts is slightly upwards and this is most marked in North Queensland, the Burdekin and South Queensland. The upward trend in North Queensland and South Queensland is probably a result of increased liming in those districts as a result of BSES research and recommendations. The trend in the Burdekin may be a result of expansion onto clay soils with higher pH.

There is a corresponding decrease in the percentage of soils with pH < 5 in all districts except the Burdekin, and an increase in the percentage of soils with pH > 7 in the Burdekin.
Electrical conductivity

The trend in EC values in each district from 1982-2002 is indicated in Figure 14. There is no consistent trend evident in EC values, and this suggests that there has been no significant expansion in the area of soils affected by salinity in the sugar industry.

Calcium

The trend in soil Ca values from 1982-2002 in each district, the trend in percentage of samples showing Ca deficiency, and the trend in the percentage of samples showing marginal soil Ca levels are indicated in Figures 15, 16 and 17.

As expected from the soil pH figures, there is slight upward trend in average soil Ca levels in North Queensland, the Burdekin and South Queensland. Similarly, there is a decline in the percentage of samples showing apparent calcium deficiency in North Queensland and South Queensland. This is likely to result in improved productivity in these districts when weather conditions are favourable.
Magnesium

The trends in average soil Mg levels, percentage of deficient sites, and percentage of sites with marginal magnesium levels for each district are given in Figures 18, 19 and 20. These show a gradual upward trend in soil magnesium levels in North Queensland where Mg deficiency was most prevalent, and a corresponding decrease in the percentage of samples with apparent Mg deficiency, or marginal Mg levels.

Similar but less pronounced trends are evident for the Herbert and South Queensland, reflecting adoption of recommendations for correction of Mg deficiency.
Potassium

The trends in soil extractable K, percentage of sites with low extractable K, and in nitric K reserves in each district are given in Figures 21, 22 and 23.
There is a slight downward trend in extractable K in the Herbert and South Queensland, and this is reflected in an apparent increase in the number of K deficient sites in these districts in recent years. There is no obvious trend in nitric K values over the 1996-2002 period.

**Figure 21. Trend in Extractable K**

**Figure 22. Trend in % low soil K sites (<0.12 me%)**

**Figure 23. Trend in Nitric K**
**Exchangeable sodium percentage (ESP)**

The trend in ESP in each district over the period 1994-2002 is given in Figures 24 and 25, together with the percentage of samples with ESP > 15. These show a gradual increase in ESP in the Central region over time, and an increase in the proportion of high ESP samples in the Southern region in the last two years. There is an apparent decline in ESP in the Burdekin over this period. These figures are not a major concern in the Central and Southern regions but suggest that more care is required in managing sodic soils in these districts.

![Figure 24. Trend in Exch. Na% (ESP)](image)

![Figure 25. Trend in % High ESP Sites (>15)](image)

**Aluminium saturation**

The trends in aluminium saturation % over the period 1995-2002 are indicated in Figure 26. There is an apparent gradual decrease in mean Al saturation % over this period in North Queensland, the Herbert and South Queensland and this corresponds to the increase in pH and soil calcium levels resulting from liming.
Phosphorus

The trends in average BSES P levels from 1982-2002 in each district and in percentage low P sites are given in Figures 27 and 28. There is no obvious trend in average BSES P levels, but there is a possible increase in the percentage of low P sites in the Herbert and South Queensland. Regular soil sampling to guide P application, and P application at planting as recommended will minimise any yield losses from P deficiency.
**Sulfur**

The trends in average $\text{SO}_4$-$\text{S}$ levels and in the percentage of samples with low $\text{SO}_4$-$\text{S}$ ($< 3$ mg/kg) for each district are summarised in Figures 29 and 30. These figures show a downward trend in $\text{SO}_4$-$\text{S}$ levels in most districts over the period 1982-2002, and a corresponding increase in the percentage of low S sites. This indicates that the current policy of recommending use of S fortified fertiliser in low S soils needs to be maintained, and expanded to the Burdekin region.

**Figure 29. Trend in Soil Sulfate-S**

![Figure 29. Trend in Soil Sulfate-S](image)

**Figure 30. Trend in % low soil S sites ($< 3$ mg/kg)**

![Figure 30. Trend in % low soil S sites ($< 3$ mg/kg)](image)

**Nitrate N**

The trends in average nitrate-N levels and in percentage low NO$_3$-N sites in each district are shown in Figures 31 and 32. The most clear-cut trend in these figures is an apparent decline in average NO$_3$-N levels in the Burdekin, and an increase in the percentage of low NO$_3$-N sites in this district. The reason for this is uncertain but it may reflect a change in rotation, and the introduction of less fertile expansion land in the Burdekin.
Figure 31. Trend in Soil NO$_3$-N

Iron

The trend in average iron levels in each district is shown in Figure 33. There is an apparent gradual decline in iron levels in each district, but the iron status of soils is still good.
Manganese

The trends in average DTPA Mn levels, and in percentage low Mn sites in each district are illustrated in Figures 34 and 35. These figures confirm the low Mn status of soils in the Bundaberg region, but trends are not clear-cut over time due to the variability of Mn analyses. The presence of low Mn analyses is of concern, but the variability of Mn values suggests that any apparent Mn deficiency should be confirmed by leaf analysis or the presence of deficiency symptoms before Mn fertiliser is applied.
Copper

The trends in DTPA extractable Cu, and in the percentage of low Cu soils in each district are shown in Figures 36 and 37. With the exception of the Burdekin there is an apparent gradual decline in DTPA Cu levels in each district, and a slight increase in the percentage of low Cu sites.

This suggests that canegrowers need to continue with regular copper applications on marginal soils (particularly sands).
Zinc

The trends in average BSES soil zinc levels and in percentage low zinc soils over the period 1995-2002 in each district are shown in Figures 38 and 39. These trends indicate that BSES Zn levels may have increased slightly in the last three years in areas such as North Queensland, the Herbert and North Queensland. Similarly, the percentage of deficient sites has declined. This may reflect the publicity given to zinc deficiency and the importance of soil testing in recent years.
Boron

The trend in boron levels over the period 1995-2002 in each district is shown in Figure 40. There is no clear trend in soil B levels.

4.2.1.4 Effect of soil texture on average analyses and % low and high soil analyses in each district

The effect of soil texture on soil analyses was evaluated by interrogating the soil database to obtain average analyses for clay, loam and sand soil groups. It was noted that a number of sites apparently had no defined soil texture, and there were limited numbers of defined sites, particularly for sands, in some districts. In the future, better definition of soil texture on samples submitted for soil testing by Incitec will improve the usefulness of the database. The extracted texture data are therefore less reliable in indicating trends and only mean values for selected soil analyses were extracted from the database. The extracted data refer to the whole period of soil analysis and do not take into account changes in recent years. These are summarised in Table 5.
The figures in Table 5 indicate that levels of organic C, Ca, Mg, exchangeable K, S and Mn generally declined with decreasing clay content in the soil. For all these analyses the percentage of sites with low or deficient levels was significantly higher in sandy soils than for the loams and clays. This suggests that the overall fertility of sandy soils is lower and will be more difficult to maintain either in terms of organic matter content or nutrient levels.

The exception to the above observations was the calcium analysis of North Queensland soils where all three soil textures showed a relatively high proportion of Ca deficiency.

For BSES P there was no consistent effect of soil texture on average analyses and percentage of deficient sites.

The average soil electrical conductivity values in each district generally increased with increasing clay content as expected.

The exchangeable sodium percentage generally decreased with decreasing soil clay content, with the exception of the Central and Southern regions where ESP was highest in the sandy soils. This may reflect the different origins of sandy soils in these districts and their association with sodic subsoil.
<table>
<thead>
<tr>
<th>District/Texture</th>
<th>Org C %</th>
<th>EC mS/m</th>
<th>Ca me%</th>
<th>Mg me%</th>
<th>Exch K me%</th>
<th>ESP</th>
<th>P mg/kg</th>
<th>S mg/kg</th>
<th>DTPA Cu mg/kg</th>
<th>DTPA Zn mg/kg</th>
<th>Mn mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North Qld</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>1.66</td>
<td>0.06</td>
<td>1.73 (15)</td>
<td>0.75 (2)</td>
<td>0.22 (12)</td>
<td>1.9</td>
<td>62 (7)</td>
<td>22.4 (4)</td>
<td>0.9 (14)</td>
<td>1.0 (10)</td>
<td>24.6 (19)</td>
</tr>
<tr>
<td>Loam</td>
<td>1.84</td>
<td>0.05</td>
<td>1.56 (20)</td>
<td>0.63 (6)</td>
<td>0.21 (19)</td>
<td>1.9</td>
<td>60 (7)</td>
<td>21.5 (5)</td>
<td>0.8 (17)</td>
<td>1.0 (10)</td>
<td>17.7 (30)</td>
</tr>
<tr>
<td>Sand</td>
<td>1.09</td>
<td>0.03</td>
<td>1.08 (25)</td>
<td>0.33 (21)</td>
<td>0.13 (63)</td>
<td>2.6</td>
<td>42 (36)</td>
<td>6.5 (31)</td>
<td>0.3 (61)</td>
<td>0.5 (44)</td>
<td>4.6 (76)</td>
</tr>
<tr>
<td><strong>Herbert</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>1.26</td>
<td>0.06</td>
<td>3.8 (0.7)</td>
<td>2.45 (0)</td>
<td>0.25 (8)</td>
<td>1.0 (4)</td>
<td>39 (19)</td>
<td>16.9 (1)</td>
<td>1.4 (3)</td>
<td>2.5 (1)</td>
<td>26.9 (3)</td>
</tr>
<tr>
<td>Loam</td>
<td>1.28</td>
<td>0.04</td>
<td>2.13 (11)</td>
<td>0.93 (2)</td>
<td>0.21 (19)</td>
<td>3.2 (2)</td>
<td>47 (10)</td>
<td>11.3 (8)</td>
<td>0.8 (17)</td>
<td>1.5 (6)</td>
<td>22.6 (11)</td>
</tr>
<tr>
<td>Sand</td>
<td>1.22</td>
<td>0.05</td>
<td>1.27 (35)</td>
<td>0.31 (7)</td>
<td>0.17 (52)</td>
<td>2.3 (0)</td>
<td>65 (7)</td>
<td>7.6 (29)</td>
<td>0.4 (58)</td>
<td>0.8 (30)</td>
<td>8.3 (39)</td>
</tr>
<tr>
<td><strong>Burdekin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>1.02</td>
<td>0.16</td>
<td>11.1 (0.1)</td>
<td>7.3 (0)</td>
<td>0.32 (1)</td>
<td>9.5 (19)</td>
<td>61 (15)</td>
<td>14.6 (11)</td>
<td>1.5 (0)</td>
<td>1.1 (8)</td>
<td>13.5 (27)</td>
</tr>
<tr>
<td>Loam</td>
<td>0.99</td>
<td>0.11</td>
<td>7.4 (0.6)</td>
<td>3.8 (0)</td>
<td>0.29 (4.9)</td>
<td>7.2 (9)</td>
<td>80 (6)</td>
<td>11.5 (21)</td>
<td>1.2 (3)</td>
<td>1.5 (5)</td>
<td>14.0 (21)</td>
</tr>
<tr>
<td>Sand</td>
<td>0.57</td>
<td>0.06</td>
<td>2.8 (5)</td>
<td>1.14 (2.5)</td>
<td>0.21 (29)</td>
<td>5.7 (0)</td>
<td>56 (13)</td>
<td>6.4 (49)</td>
<td>0.6 (29)</td>
<td>1.4 (4)</td>
<td>8.7 (46)</td>
</tr>
<tr>
<td><strong>Central Qld</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>1.33</td>
<td>0.07</td>
<td>7.0 (0.3)</td>
<td>4.6 (0.5)</td>
<td>0.26 (13)</td>
<td>3.8 (4)</td>
<td>35 (14)</td>
<td>12.8 (4)</td>
<td>1.6 (7)</td>
<td>1.2 (10)</td>
<td>22.5 (18)</td>
</tr>
<tr>
<td>Loam</td>
<td>1.20</td>
<td>0.04</td>
<td>2.8 (5)</td>
<td>1.51 (0.5)</td>
<td>0.22 (24)</td>
<td>3.5 (2)</td>
<td>49 (10)</td>
<td>9.1 (9)</td>
<td>0.9 (14)</td>
<td>1.4 (8)</td>
<td>20.1 (15)</td>
</tr>
<tr>
<td>Sand</td>
<td>0.72</td>
<td>0.04</td>
<td>1.09 (32)</td>
<td>0.41 (8)</td>
<td>0.12 (66)</td>
<td>5.4 (11)</td>
<td>52 (15)</td>
<td>6.0 (38)</td>
<td>0.7 (25)</td>
<td>1.4 (17)</td>
<td>6.7 (55)</td>
</tr>
<tr>
<td><strong>South Qld</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>1.75</td>
<td>0.10</td>
<td>5.33 (2)</td>
<td>4.72 (0.1)</td>
<td>0.36 (5)</td>
<td>5.8 (6)</td>
<td>57 (7)</td>
<td>27.9 (3)</td>
<td>2.6 (3)</td>
<td>2.7 (4)</td>
<td>37.2 (9)</td>
</tr>
<tr>
<td>Loam</td>
<td>1.56</td>
<td>0.08</td>
<td>2.8 (10)</td>
<td>1.5 (1)</td>
<td>0.26 (22)</td>
<td>5.8 (5)</td>
<td>65 (8)</td>
<td>20.1 (9)</td>
<td>1.5 (21)</td>
<td>1.9 (11)</td>
<td>17.7 (41)</td>
</tr>
<tr>
<td>Sand</td>
<td>1.18</td>
<td>0.05</td>
<td>1.27 (30)</td>
<td>0.49 (4)</td>
<td>0.14 (55)</td>
<td>9.7 (16)</td>
<td>63 (10)</td>
<td>8.9 (27)</td>
<td>0.8 (36)</td>
<td>1.3 (22)</td>
<td>4.3 (77)</td>
</tr>
</tbody>
</table>

* bracketed figures are % sites with low values
4.2.1.5 Conclusions

The main conclusions from the analysis of the Incitec database are as follows.

- The Incitec database gives an excellent representation of general soil fertility of soils in each sugar producing region and of potential problems due to nutrient deficiency, or possible toxicity or other adverse effects. Most soil tests are carried out on from 200 to 1,000 samples per district in the different districts each year.

- Soil organic matter levels are generally relatively low throughout the sugar industry, ranging from an average of 0.99% organic C in the Burdekin to 1.71% in North Queensland soils. Organic C levels are relatively stable over time in most districts, with the exception of the Burdekin where organic C levels appear to be declining slightly.

- Soil pH is generally acid throughout the industry and ranges from 5.2 in the Herbert to 5.7 in South Queensland. The exception is the Burdekin where the soil pH was 6.9 on average over the period 1982 to 2002, and close to neutral. The pH is increasing gradually in most districts and the average pH in the Burdekin is now around 7.0. While the increase in pH in the other districts is an indication of the success of liming programs, in the Burdekin it may be contributing to decreased effectiveness of pesticides.

- In general, the soil analyses do not show serious problems with salinity or sodicity in any district, but confirm the presence of significant salinity and sodicity problems in limited sections of the Burdekin, Central and Southern regions. In most cases the higher levels occur in clay soils, but sandy soils in the Central and Southern regions have moderately high sodicity.

- There is a significant proportion of soils with moderately high aluminium saturation levels in all districts except the Burdekin, reflecting the acid soil pH. However, this is unlikely to affect productivity in areas other than those affected by disturbance of acid sulfate soil. The aluminium levels have fallen in most districts, apparently due to the effects of liming.

- Average soil calcium levels over the sampling period are satisfactory for all districts except North Queensland. The percentage of soils with deficient or marginal levels of soil Ca is highest in North Queensland, but there is a significant proportion of soils with low Ca levels in all districts apart from the Burdekin. In general, the Ca status of soils has improved markedly over time in most districts, and particularly in North and South Queensland, apparently due to more widespread lime applications.

- Low soil magnesium levels are less widespread than for calcium, but there is still a significant proportion of soils with low Mg in North Queensland and the Herbert. Soil Mg status in the higher risk districts has improved over time.

- The soil potassium levels have remained relatively stable in most districts and, with the exception of the Burdekin, all districts require regular potassium application to maintain productivity. Reserves of potassium, measured as nitric acid K, are highest in the Burdekin and lowest in the Southern region.
• The average soil phosphorus reserves (measured as BSES P) are satisfactory in most districts, ranging from 46 mg/kg in the Central region to 73 mg/kg in the Burdekin. The P reserves have been relatively stable over time and maintenance P applications are still required on most soils, guided by soil tests. There is no evidence of a build up of P as noted in the BSES monitoring sites.

• The average soil S levels are only moderate over the whole industry, ranging from 10.6 mg/kg in the Central region to 20.6 mg/kg in North Queensland. There is a significant proportion of low S soils in each district and both average soil S levels, and the percentage of soils with low S levels have increased over time. This suggests that growers should be using more S fortified fertilisers, and that S applications need to be increased in areas such as the Burdekin where S levels are showing the greatest decline.

• The average level of nitrate nitrogen is low in all districts and this level is relatively stable over time except for the Burdekin where NO3-N levels are apparently declining. While nitrate levels could be higher in the subsoil, in most cases the low nitrate level in surface soil means that most farmers remain heavily dependent on nitrogen fertiliser, and there has been no apparent impact of legume rotations and trash blanketing on readily available nitrogen levels.

• The average manganese levels in sugar soils are only moderate and a significant proportion of soils have low Mn levels, from 12% in the Herbert up to 41% in South Queensland. The proportion of low Mn soils has increased over time in the most at risk districts, North and South Queensland. While Mn deficiency has not yet been recorded in sugarcane in Australia a watching brief needs to be kept using leaf analyses to detect potential Mn deficiency.

• Soil copper levels are only moderate in most districts and from 14 to 22% of soils analysed in the different districts showed low Cu levels. The exception was the Burdekin which appears to have adequate copper levels. There appears to have been an increase in the percentage of low Cu soils in districts other than the Burdekin, and continued application of copper will be necessary on at risk soils.

• The average soil zinc levels are satisfactory in each district but from 9 to 13% of samples showed low Zn levels in the different districts. There appears to have been a slight improvement in the zinc status of sugar soils since Zn deficiency was first identified, but continued Zn application guided by soil analysis will be necessary on at risk soils.

• The soil boron levels appear adequate in most districts with North Queensland having the highest proportion of low B soil tests (19%). As for manganese, no boron deficiency has been positively confirmed in the Australian sugar industry and soil tests need to be backed up with leaf tests in low B areas.

• Testing of sugar soils for silicon levels has only been in place for 1-3 years, for the two available soil tests. Tests to date indicate that silicon levels are satisfactory in the Burdekin, and from 15-37% of soils in the remaining districts have low Si levels. The most at risk area appears to be South Queensland which has from 36-37% of soils low in both readily available Si and Si reserves.
• In general, soil fertility was found to be lowest in sandy soils with organic C, calcium, magnesium, exchangeable potassium, sulfate sulfur, manganese, copper and zinc levels being lower in sandy soils, and the percentage of low values being greater. In the Burdekin, soil pH was also texture dependent, ranging from 6.4 in sands to 7.1 in clay soils. Over 50% of clay soils had a pH greater than 7.

4.2.2 BSES data

4.2.2.1 Details of soil analyses

The soil analyses conducted on the majority of samples from the selected soil monitoring field sites included in the database are listed in Table 6. The data include only the period 1975-1994 and only three of the five districts, but it should give a more consistent analysis of trends over time than the Incitec data because the same sites were sampled on each occasion.

<table>
<thead>
<tr>
<th>Soil Analyses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>pH CaCl₂</td>
<td>BSES K me%</td>
</tr>
<tr>
<td>pH H₂O</td>
<td>Nitric K me%</td>
</tr>
<tr>
<td>Base Saturation %</td>
<td>BSES Ca me%</td>
</tr>
<tr>
<td>Exchange acidity me%</td>
<td>BSES Mg me%</td>
</tr>
<tr>
<td>Effective CEC me%</td>
<td>BSES Na me%</td>
</tr>
<tr>
<td>CEC pH 7 me%</td>
<td>SO₄-S mg/kg</td>
</tr>
<tr>
<td>Conductivity (1:5) dS/m</td>
<td>Mn mg/kg</td>
</tr>
<tr>
<td>Nitrate N mg/kg</td>
<td>Al (CaCl₂) mg/kg</td>
</tr>
<tr>
<td>Organic C %</td>
<td>Si (CaCl₂) mg/kg</td>
</tr>
<tr>
<td>BSES P mg/kg</td>
<td>Cu mg/kg</td>
</tr>
<tr>
<td>P sorption mg/kg</td>
<td>Zn mg/kg</td>
</tr>
</tbody>
</table>

4.2.2.2 Average trends over all data

The average data from all sites for each sampling period for sites sampled three or four times are summarised in Table 7. When trends in average data for the different sampling periods are considered there is no apparent change for the following analyses: soil pH, EC, NO₃-N, P sorption, Fe, BSES K, Nitric K, Ca, Mg, Na, Al, Si, and Cu. There is an upward trend in BSES P and organic carbon (Figure 41), and an apparent downward trend in SO₄-S, Mn and Zn (Figure 42).
TABLE 7. Summary data for each sampling period for sites sampled three or four times.

<table>
<thead>
<tr>
<th>No. of Samplings/Sampling Period</th>
<th>pH CaCl₂</th>
<th>pH H₂O</th>
<th>Base Sat %</th>
<th>Exch. Acid. me%</th>
<th>Effect. CEC pH 7 me%</th>
<th>CEC pH 7 me%</th>
<th>EC dS/m</th>
<th>NO₃-N mg/kg</th>
<th>Org C %</th>
<th>BSES P mg/kg</th>
<th>P Sorption mg/kg</th>
<th>Fe mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Samplings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>4.03</td>
<td>5.22</td>
<td>26</td>
<td>1.25</td>
<td>3.28</td>
<td>9.95</td>
<td>0.05</td>
<td>7.5</td>
<td>1.21</td>
<td>66</td>
<td>175</td>
<td>65</td>
</tr>
<tr>
<td>1980-1984</td>
<td>4.03</td>
<td>5.05</td>
<td>33</td>
<td>1.38</td>
<td>3.74</td>
<td>7.32</td>
<td>0.06</td>
<td>11.7</td>
<td>1.22</td>
<td>81</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>1985-1989</td>
<td>4.27</td>
<td>5.13</td>
<td>1.25</td>
<td>3.28</td>
<td>9.95</td>
<td>0.05</td>
<td>7.5</td>
<td>1.21</td>
<td>66</td>
<td>189</td>
<td>58</td>
<td>77</td>
</tr>
<tr>
<td>1990-1994</td>
<td>4.32</td>
<td>5.10</td>
<td>1.25</td>
<td>3.28</td>
<td>9.95</td>
<td>0.05</td>
<td>7.5</td>
<td>1.21</td>
<td>66</td>
<td>189</td>
<td>58</td>
<td>77</td>
</tr>
<tr>
<td>3 Samplings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>4.12</td>
<td>5.32</td>
<td>31</td>
<td>0.93</td>
<td>4.45</td>
<td>11.21</td>
<td>0.05</td>
<td>5.1</td>
<td>1.08</td>
<td>67</td>
<td>151</td>
<td>65</td>
</tr>
<tr>
<td>1980-1984</td>
<td>4.18</td>
<td>5.32</td>
<td>53</td>
<td>0.93</td>
<td>4.45</td>
<td>11.21</td>
<td>0.05</td>
<td>5.1</td>
<td>1.08</td>
<td>67</td>
<td>151</td>
<td>65</td>
</tr>
<tr>
<td>1985-1989</td>
<td>4.46</td>
<td>5.37</td>
<td></td>
<td>0.93</td>
<td>4.45</td>
<td>11.21</td>
<td>0.05</td>
<td>5.1</td>
<td>1.08</td>
<td>67</td>
<td>151</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>BSES K me%</td>
<td>Nitric K me%</td>
<td>BSES Ca me%</td>
<td>BSES Mg me%</td>
<td>BSES Na me%</td>
<td>SO₄-S mg/kg</td>
<td>Mn mg/kg</td>
<td>Al mg/kg</td>
<td>Si mg/kg</td>
<td>Cu mg/kg</td>
<td>Zn mg/kg</td>
<td>B mg/kg</td>
</tr>
<tr>
<td>4 Samplings</td>
<td>0.15</td>
<td>1.93</td>
<td>1.60</td>
<td>0.50</td>
<td>0.08</td>
<td>45</td>
<td>48</td>
<td>20</td>
<td>11</td>
<td>0.75</td>
<td>1.82</td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>0.15</td>
<td>1.91</td>
<td>1.54</td>
<td>0.50</td>
<td>0.07</td>
<td>31</td>
<td>42</td>
<td>23</td>
<td>12</td>
<td>0.89</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>1980-1984</td>
<td>0.15</td>
<td>1.79</td>
<td>1.38</td>
<td>0.44</td>
<td>0.06</td>
<td>29</td>
<td>27</td>
<td>24</td>
<td>12</td>
<td>0.93</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>1985-1989</td>
<td>0.15</td>
<td>1.81</td>
<td>1.65</td>
<td>0.49</td>
<td>0.07</td>
<td>26</td>
<td>23</td>
<td>21</td>
<td>9</td>
<td>0.75</td>
<td>0.80</td>
<td>0.19</td>
</tr>
<tr>
<td>3 Samplings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>0.15</td>
<td>1.67</td>
<td>2.23</td>
<td>1.02</td>
<td>0.14</td>
<td>41</td>
<td>59</td>
<td>17</td>
<td>15</td>
<td>1.04</td>
<td>1.77</td>
<td></td>
</tr>
<tr>
<td>1980-1984</td>
<td>0.18</td>
<td>1.64</td>
<td>2.44</td>
<td>1.01</td>
<td>0.12</td>
<td>33</td>
<td>47</td>
<td>17</td>
<td>15</td>
<td>1.23</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>1985-1989</td>
<td>0.19</td>
<td>1.74</td>
<td>2.29</td>
<td>1.05</td>
<td>0.10</td>
<td>27</td>
<td>41</td>
<td>17</td>
<td>15</td>
<td>1.28</td>
<td>1.00</td>
<td>0.24</td>
</tr>
</tbody>
</table>
The following observations can be made from the above data.

- Liming practices are apparently countering any potential decline in soil pH and soil calcium levels over all districts, but both pH and calcium levels are lower for the predominantly North Queensland sites that were sampled on four occasions. While calcium levels on average in North Queensland are adequate for cane growth there are number of sites with marginal or deficient levels of calcium.

- Similarly there has been no apparent decline in soil Mg and K levels over time. This suggests adequate potassium fertiliser applications to counter any luxury consumption of K by cane. Magnesium levels are lower for the predominantly North Queensland sites but on average are adequate for cane growth.
• The lack of any trends in EC or extractable sodium values over time, and the overall low values, suggest no salinity problems in the areas covered by the monitoring sites.

• While there is no obvious trend in soil silicon levels over time the average levels are marginal, particularly in North Queensland. This agrees with recent surveys of soil silicon levels in different districts which suggest potential for significant yield responses to broadcast silicon application.

• The apparent downward trend in SO₄-S, Mn and Zn levels in the monitoring sites is of concern, but average values are still well above expected deficiency levels.

• The upward trend in BSES P values suggests that average farmer applications up to the last sampling date were above crop requirements, despite BSES recommendations for reduced rates based on soil analyses.

• The upward trend in organic carbon values may reflect the increased adoption of green cane trash blanketing practices, and this should assist with maintenance of soil fertility. It is interesting to note that organic carbon levels are generally higher for the four sampling dates corresponding to North Queensland samples where the percentage of green cane harvesting is higher than for the Central region. Over all districts, organic carbon levels increased by 11% over the ten year sampling period.

4.2.2.3 Analysis of district effects

The average data for the North Queensland (Mossman to Tully), Herbert and Central Queensland (Proserpine-Mackay) monitoring sites for selected analyses and three sampling periods are summarised in Table 8. The following observations can be made for these data.

• The soil pH was relatively stable for North Queensland and the Central region over time, but fell significantly in the Herbert region. The trend in the Herbert has been noted in other surveys and is of concern for long-term cropping.

• Organic carbon levels have increased significantly in each region over the sampling period. The final organic carbon levels follow the order North Queensland > Central region > Herbert region.

• BSES P levels have increased in each district, but most significantly in the Central region. Using P values < 20 mg/kg as an indicator, approximately 9% of sites would be expected to respond to phosphorus fertiliser in North Queensland and the Central region, and no sites in the Herbert. These figures are significantly lower than the figures of 10-25% reported by Chapman et al. (1981) for the initial sampling in these regions.

• Both BSES K and nitric K values have remained relatively stable in each district, and there is an unexpected apparent rise in values over time in the Central region. The reason for this is uncertain, but dunder is widely used as a potassium source in this region. Around 70% of sites would be expected to respond to potassium fertiliser (BSES K < 0.2 me%). Based on reserves of potassium <0.6 me% measured as nitric K, 26% of North Queensland sites had low or marginal reserves and 11% of the Central region sites. Reserves were adequate in the Herbert region sites.
TABLE 8. Selected summary data for North Queensland, the Herbert and the Central region for three sampling periods.

<table>
<thead>
<tr>
<th>District/Year</th>
<th>pH</th>
<th>Org C%</th>
<th>BSES P mg/kg</th>
<th>BSES K me%</th>
<th>Nitric K me%</th>
<th>BSES Ca me%</th>
<th>BSES Mg me%</th>
<th>SO₄-S mg/kg</th>
<th>Mn mg/kg</th>
<th>Si mg/kg</th>
<th>Zn mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Queensland</td>
<td>1975-1979</td>
<td>5.11</td>
<td>1.32</td>
<td>72</td>
<td>0.14</td>
<td>1.99</td>
<td>1.11</td>
<td>0.26</td>
<td>63</td>
<td>57</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>1980-1984</td>
<td>5.29</td>
<td>1.39</td>
<td>97</td>
<td>0.17</td>
<td>1.90</td>
<td>1.73</td>
<td>0.34</td>
<td>50</td>
<td>40</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1985-1989</td>
<td>5.66</td>
<td>1.40</td>
<td>90</td>
<td>0.17</td>
<td>1.94</td>
<td>1.30</td>
<td>0.30</td>
<td>42</td>
<td>33</td>
<td>11</td>
</tr>
<tr>
<td>Herbert</td>
<td>1975-1979</td>
<td>5.32</td>
<td>0.71</td>
<td>53</td>
<td>0.16</td>
<td>1.69</td>
<td>2.14</td>
<td>1.08</td>
<td>22</td>
<td>69</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>1980-1984</td>
<td>5.14</td>
<td>0.73</td>
<td>50</td>
<td>0.14</td>
<td>1.67</td>
<td>2.00</td>
<td>0.99</td>
<td>13</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>1985-1989</td>
<td>4.95</td>
<td>0.82</td>
<td>64</td>
<td>0.15</td>
<td>1.60</td>
<td>1.95</td>
<td>0.76</td>
<td>12</td>
<td>45</td>
<td>14</td>
</tr>
<tr>
<td>Central region</td>
<td>1975-1979</td>
<td>5.66</td>
<td>0.83</td>
<td>66</td>
<td>0.16</td>
<td>1.13</td>
<td>4.15</td>
<td>2.27</td>
<td>11</td>
<td>60</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>1980-1984</td>
<td>5.77</td>
<td>0.83</td>
<td>85</td>
<td>0.21</td>
<td>1.26</td>
<td>4.02</td>
<td>2.25</td>
<td>13</td>
<td>56</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>1985-1989</td>
<td>5.79</td>
<td>1.00</td>
<td>108</td>
<td>0.24</td>
<td>1.47</td>
<td>4.09</td>
<td>2.42</td>
<td>9</td>
<td>53</td>
<td>23</td>
</tr>
</tbody>
</table>
Soil calcium levels were relatively stable in each district over the sampling period and average values are adequate for crop growth. North Queensland and the Herbert have significantly lower calcium levels than the Central region. Using soil calcium levels of <0.65 me% as an indicator, the percentage of deficient sites at the final sampling was 34%, 14% and 3%, respectively, for North Queensland, the Herbert and the Central region. In addition, 34%, 29% and 14% of sites for the respective districts had marginal calcium levels between 0.65 me% and 1.5 me%. These figures are similar to those reported earlier by Chapman et al. (1981), and calcium deficiency remains of concern, particularly in North Queensland and the Herbert.

Soil magnesium levels were also relatively stable over all sampling periods in North Queensland and the Central region, but declined in the Herbert region. Approximately 65%, 14% and 3% of sites in North Queensland, the Herbert and the Central region, respectively, had marginal levels of soil magnesium (<0.3 me%). In North Queensland 19% of the sites were deficient in magnesium (<0.1 me%). As for calcium, the soil magnesium status does not appear to have improved significantly since the initial sampling reported by Chapman et al. (1981).

The levels of SO4-S in all regions have declined over time and average levels in the Herbert and Central regions were marginal at the final sampling. Approximately 12%, 21% and 34% of sites in North Queensland, the Herbert and the Central region, respectively, had marginal levels of sulfur (<7 mg/kg) in 1985-89. This is similar to the sulfur story reported by Chapman (1996) and suggests that emphasis should still be placed on using sulfur fortified fertiliser mixtures for marginal soils in all districts.

While silicon levels in soils were relatively stable over time in all districts the relatively low values for North Queensland are of concern. Using a silicon level of <10 mg/kg as an indicator, approximately 51%, 14% and 6% of sites in North Queensland, the Herbert and the Central region had marginal levels of silicon in the 1985-89 sampling. Haysom and Chapman (1975) reported responses to calcium silicate application in Mackay soils with silicon levels <10 mg/kg, and widespread responses would be expected in North Queensland. Recent research by Berthelsen et al. (1999) and Berthelsen et al. (2001) has demonstrated that a number of soil types in North Queensland should respond to silicate fertiliser.

Soil zinc levels declined over time in each region and 27%, 7% and 3% of sites in the respective regions showed marginal zinc levels (<0.4 mg/kg) at the final sampling. As reported previously by Reghonzani (1993) low zinc levels are of particular concern in North Queensland.

Soil manganese levels declined over time in all three regions and marginal levels (<5 mg/kg) were found in 25%, 0% and 6% of sites, respectively, for the three regions. While Mn deficiency has never been recorded in sugarcane in Australia, and soil analyses are influenced by climatic conditions, the low values in a significant proportion of North Queensland sites are of concern.
4.2.2.4 Analysis of soil texture effects on soil analyses in North Queensland and the Herbert

The 35 sites in North Queensland sampled on four occasions were divided into three soil textural classes, sandy loams, loams, and clay loams to clays. Selected, average soil analyses for these classes are given in Table 9. Trends in soil analyses based on soil texture are discussed below.

- The trends in organic carbon values over time and the final organic carbon levels are similar for each soil textural class. There was an increase in organic carbon levels of 35% over the 15-year sampling period. A majority of this increase occurred in the last five years. It is not clear why such a rapid increase was recorded, because details of site trash blanketing history were not available, but the increase was spread over a majority of sites.

- BSES P increased significantly over time in both the sandy loam and clay loam to clay groups, but there was no apparent trend in the loam group. BSES P was also significantly higher in the sandy loam group. This may reflect use of superphosphate in the sandy loam soils to supplement Ca in addition to P.

- The slight decline in nitric K values over time was consistent for the three texture classes and average nitric K values increased with increasing soil clay content.

- There was no clear trend in soil calcium levels over time in any of the texture classes but soil calcium was lower on average in the sandy soils. In the first two texture classes 29% of soils showed calcium deficiency while only 5% of the clay loam to clay soils showed deficiency.

- Similarly, soil magnesium levels were lower on average in the sandy soils and 83%, 50% and 43% of the sandy loam, loam and clay loam to clay groups, respectively, had marginal magnesium levels at the final sampling.

- SO₄-S values declined significantly over the 15-year period in each texture group, with the sands having the lowest average sulfate level. Fifty per cent of the sand to sandy loam sites had marginal to deficient sulfate levels.

- Similarly, manganese levels declined over time in each texture group with the lowest levels in the sandy soils. Manganese levels were marginal in 87%, 12.5% and 24% of sands, loams and clay loam to clay soils, respectively.

- Soil silicon levels fell slightly over time in all soil texture groups and were relatively low overall. In the three texture groups, 83%, 12.5% and 71% of sites had marginal levels of extractable silicon at the final sampling (< 10 mg/kg).

- There was no clear trend in soil copper levels over time but copper was lowest in the sandy soils, with 50% having marginal copper levels. Only 12.5% of the loams and 19% of the clay loam to clays had marginal copper levels.

- Soil zinc levels declined over time in all three textural groups and a significant proportion of soils in each group had marginal Zn levels. The respective percentages of marginal sites for zinc were 67, 37.5 and 48% for the three textural groups.
TABLE 9. Summary data sorted into soil textural groups for selected analyses from North Queensland and Herbert sites sampled on four occasions.

<table>
<thead>
<tr>
<th>Texture group/Date</th>
<th>Org C %</th>
<th>BSES P mg/kg</th>
<th>Nitric K me%</th>
<th>BSES Ca me%</th>
<th>BSES Mg me%</th>
<th>SO_4-S mg/kg</th>
<th>Mn mg/kg</th>
<th>Si mg/kg</th>
<th>Cu mg/kg</th>
<th>Zn mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>1.19</td>
<td>95</td>
<td>1.09</td>
<td>1.06</td>
<td>0.09</td>
<td>15</td>
<td>14</td>
<td>7</td>
<td>0.28</td>
<td>1.0</td>
</tr>
<tr>
<td>1980-1984</td>
<td>1.20</td>
<td>125</td>
<td>1.13</td>
<td>1.49</td>
<td>0.22</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>0.48</td>
<td>0.6</td>
</tr>
<tr>
<td>1985-1989</td>
<td>1.26</td>
<td>141</td>
<td>1.01</td>
<td>1.02</td>
<td>0.16</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>0.41</td>
<td>0.5</td>
</tr>
<tr>
<td>1990-1994</td>
<td>1.67</td>
<td>193</td>
<td>1.05</td>
<td>1.62</td>
<td>0.26</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>0.29</td>
<td>0.5</td>
</tr>
<tr>
<td>Loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>1.26</td>
<td>60</td>
<td>1.41</td>
<td>1.44</td>
<td>0.51</td>
<td>92</td>
<td>67</td>
<td>12</td>
<td>0.86</td>
<td>1.4</td>
</tr>
<tr>
<td>1980-1984</td>
<td>1.20</td>
<td>52</td>
<td>1.39</td>
<td>1.25</td>
<td>0.49</td>
<td>41</td>
<td>60</td>
<td>13</td>
<td>0.93</td>
<td>1.4</td>
</tr>
<tr>
<td>1985-1989</td>
<td>1.37</td>
<td>65</td>
<td>1.31</td>
<td>1.45</td>
<td>0.49</td>
<td>54</td>
<td>37</td>
<td>15</td>
<td>1.04</td>
<td>1.0</td>
</tr>
<tr>
<td>1990-1994</td>
<td>1.68</td>
<td>52</td>
<td>1.33</td>
<td>1.83</td>
<td>0.56</td>
<td>56</td>
<td>28</td>
<td>11</td>
<td>0.86</td>
<td>0.9</td>
</tr>
<tr>
<td>Clay loam to clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-1979</td>
<td>1.20</td>
<td>59</td>
<td>2.32</td>
<td>1.81</td>
<td>0.61</td>
<td>38</td>
<td>51</td>
<td>12</td>
<td>0.84</td>
<td>2.1</td>
</tr>
<tr>
<td>1980-1984</td>
<td>1.22</td>
<td>78</td>
<td>2.28</td>
<td>1.64</td>
<td>0.58</td>
<td>32</td>
<td>44</td>
<td>12</td>
<td>0.99</td>
<td>1.4</td>
</tr>
<tr>
<td>1985-1989</td>
<td>1.26</td>
<td>69</td>
<td>2.15</td>
<td>1.46</td>
<td>0.51</td>
<td>26</td>
<td>29</td>
<td>12</td>
<td>1.04</td>
<td>1.2</td>
</tr>
<tr>
<td>1990-1994</td>
<td>1.63</td>
<td>84</td>
<td>2.17</td>
<td>1.93</td>
<td>0.52</td>
<td>21</td>
<td>26</td>
<td>9</td>
<td>0.84</td>
<td>0.8</td>
</tr>
</tbody>
</table>
4.2.2.5 Conclusions

The main conclusions from analysis of the soil monitoring site database were as follows.

- BSES P levels increased over time in North Queensland, the Herbert and the Central region with the trend being more pronounced in the Central region. For North Queensland and Herbert soils BSES P was generally higher in sandy loam soils, and they also showed a greater increase in P levels over the 15-year sampling period. This suggests that up until the 1990-1994 period P fertiliser applications were still in excess of crop P removal.

- Soil organic carbon levels increased over the first 10-year period in all three regions with the average increase being 11%. In North Queensland and Herbert sites sampled for 15 years the apparent increase was 35%, the majority of this occurring between 1985-89 and 1990-94. This may be related to increases in green cane trash blanketing.

- Soil potassium levels were relatively stable over time and BSES K values indicated that around 70% of sites should respond to potassium fertiliser. Both BSES K and nitric K levels increased significantly over time in the Central region, and this trend may be related to the use of dunder as a potassium source in this region.

- Soil calcium and magnesium levels were relatively stable over time, but the proportion of sites with marginal or deficient levels of Ca and Mg does not appear to have changed significantly in the first 10-year period. Over 60% of sites in North Queensland had marginal or deficient levels of calcium and magnesium after 10 years. Deficiencies were more common in sandy soils.

- Soil silicon levels were also relatively stable over the sampling period, but were low in North Queensland, and 51% of North Queensland sites would be expected to respond to silicate application. In North Queensland sites the low silicate levels were specific to soils with sandy loam or clay loams to clay texture, and loam soils generally had satisfactory levels.

- There was a significant decline in soil SO₄-S levels over time, and 20% of sites had marginal S levels after 10 years. In North Queensland and the Herbert low S levels after 15 years were most common on sandy soils. These trends support the continued recommendation of S fortified fertilisers, particularly on soils with marginal SO₄-S levels.

- Soil zinc levels also declined over time in all regions, with marginal zinc levels being most pronounced in North Queensland sites. These trends support regular soil testing for zinc, particularly in North Queensland.

- Soil manganese levels also declined over time in all regions, and marginal levels were found in 25% of North Queensland sites at the 10-year sampling. While manganese deficiency has not been confirmed in sugarcane, a watching brief should be kept for symptoms, particularly in sandy soils in North Queensland.
5.0 OUTPUTS

Two complex databases of soil test data of relevance to Australia's sugar industry have been constructed. One contains soil research data using MS Access for BSES and the other over 460,000 records of soil test data residing with Incitec Pty Ltd. BSES staff have access to their own soil research data on CD-ROM and the sugar soil data on the Incitec web delivered system. Incitec staff have access to their entire soil test database. The ready availability of these important historic data will allow greater efficiencies to be realised in the sugar industry.

Detailed analysis of both the Incitec and BSES databases has demonstrated that, in general, soil fertility is being maintained in the sugar industry, and that historical liming programs have improved overall calcium levels in soils and increased soil pH. The more widespread use of zinc fertiliser also appears to be having an impact on soil zinc levels. Conflicting results were obtained from the two databases in relation to soil organic C levels with the Incitec database showing that organic C is declining slightly in the Burdekin and is relatively stable in other districts. The BSES database showed an apparent increase in organic C levels as a result of trash blanketing.

There are also some areas of concern with the incidence of low copper, sulfur and manganese levels apparently on the increase. Recently introduced silicon tests have also indicated that a significant proportion of sugar soils are low in silicon. These aspects of soil fertility will need to be addressed.

6.0 EXPECTED OUTCOMES

It is expected that the outcomes of this project will include more emphasis on copper, sulfur and silicon nutrition of sugarcane, and a new awareness of the potential for manganese deficiency among industry advisory staff. Current NPK fertiliser programs and liming programs have also been endorsed as being effective in maintaining soil fertility. The Incitec database will also provide an on-going reference point for Incitec and BSES staff to assess soil fertility trends in each district. These initiatives are expected to improve management of soil fertility in the sugar industry.

7.0 FUTURE RESEARCH NEEDS

The main future research needs identified are:

- checking of manganese leaves in cane third leaves, particularly on sandy soils, to determine whether Mn deficiency is becoming an industry problem;
- similar checks on boron levels in third leaves in the most sensitive areas such as sandy soils in North Queensland to determine whether B deficiency is occurring;
- a program in the Burdekin to determine whether the apparent decline in soil organic C is real, and what measures can be taken to arrest this trend.
8.0 RECOMMENDATIONS

It is recommended that the findings of this project be circulated to BSES extension staff, cane productivity staff, industry fertiliser advisers and agronomists to promote some of the suggested initiatives for more widespread use of copper, sulfur, and silicon fertiliser and to address the above research needs.

9.0 ACKNOWLEDGMENTS

The funding from the Sugar Research and Development Corporation is gratefully acknowledged. The willing cooperation of a wide range of staff from BSES and Incitec is also much appreciated as is the support from Mr Gavin McMahon (BSES) and Mr Gary Kuhn (Incitec Pty Ltd).

10.0 REFERENCES


